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A case study in Denmark

Zhang, Chen; Liu, Li

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VENTILATION STRATEGIES AND INDOOR ENVIRONMENT IN CLASSROOMS: A CASE STUDY IN DENMARK

Chen Zhang*, Li Liu
Department of Civil Engineering, Aalborg University, Thomas Manns Vej 23, 9220 Aalborg, Denmark
E-mail: cz @civil.aau.dk

ABSTRACT

Compared with the other building types, the school building has much higher occupancy density and ventilation demand. In Demark, most of the school buildings are ventilated by natural manner. There is a risk of poor indoor environment associated with the lack of ventilation system or insufficient ventilation rate. This paper aims to investigate the indoor environment in two schools with different ventilation strategies. The indoor environment parameters, such as operative temperature, relative humidity, and CO2 level, are recorded during a filed measurement in the heating season. The impact of ventilation strategy on the school environment is addressed.

KEY WORDS: Classroom, Indoor environment, Ventilation strategy

INTRODUCTION

Compared with the other building types, the school building has much higher occupancy density and ventilation demand. In Demark, most of the school buildings are ventilated by natural manner. There is a risk of poor indoor environment associated with the lack of ventilation system or insufficient ventilation rate. By examining the air quality in 800 Danish classrooms, Toftum et al. (2015) found out a strong association between learning performance and ventilation mode. Dias et al. (2015) verified a significant increase in student absenteeism as a consequence of low ventilation rate. The good indoor environment does not only have a positive impact on the learning outcome but also influences children's health. Karimipanah et al. (2007) estimated that more than half of the school children have some types of allergy or asthma.

This paper aims to investigate the indoor environment in two schools with different ventilation strategies. The indoor environment parameters, such as operative temperature, relative humidity, and CO2 level, are recorded during a filed measurement in the heating season. The impact of ventilation strategy on the school environment is addressed.

METHODOLOGY

Two primary schools located in Aalborg, Denmark were selected as case studies. In order to evaluate the indoor environment, a measurement campaign was conducted in four representative classrooms (two classrooms in each school), as shown in Figure 1. The characteristics of each classroom are stated in Table 1. It needs to notice that only classroom A2 is equipped with mechanical ventilation, and the other three classrooms are naturally ventilated. In classroom A2, the air is supplied through a textile diffuser located in the ceiling along the length of the classroom, as indicated in Figure 2. The textile diffuser is 5m in length and is a semi-circle with a diameter of 0.4 m. There are two exhaust openings located in the wall faced to the corridor. One is placed near the ceiling but blocked by the ventilation pipe, while the other is located in the occupied zone behind the furniture.

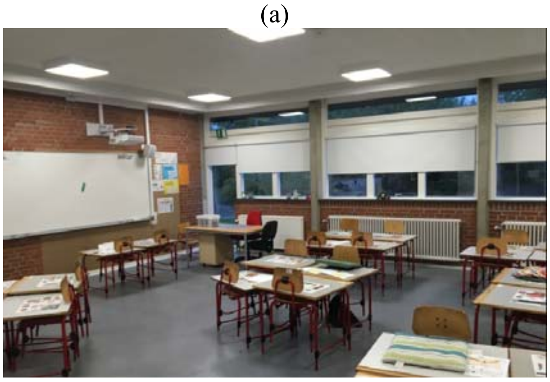
The measurement was focused on the indoor environment in the classrooms, therefore, the CO2 concentration, operative temperature, and relative humidity were monitored for a period of one month in November 2016. The draught rate was measured as an index of local thermal comfort. The devices for measuring the indoor environment were located in several places in the occupied zone with three different heights (0.1 m, 0.7 m and 1.1 m). The outdoor air temperature and relative humidity were measured at the same period.

Table 1. Classrooms characteristics

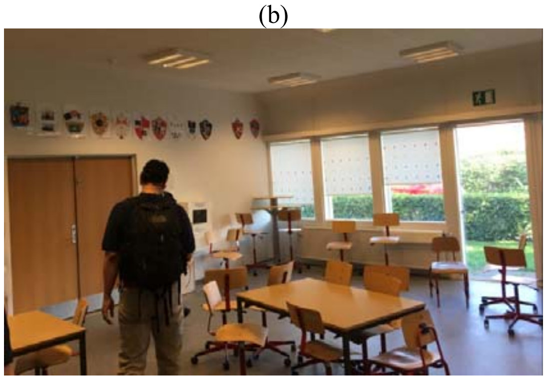
Room	Year (construction/ renovation)	Orientation	Area [m^2]	Room height [m]	Number of occupants	Ventilation strategy
A1	1914/2000	South	64.45	3.2	19	Natural ventilation
A2	1959/1997	South	47.40	3.2	15	CAV mechanical ventilation 0.64 l/s.m^2 @ 17.4 ^oC Weekday 8:00-16:00
B1	1977/2008	South	68.59	3.2	26	Natural ventilation
B2	1977/2008	East	55.87	3.2	21	Natural ventilation

(a)

(b)



(c)



(d)

Figure 1.Photos of classroom (a) A1 (b) A2 (c) B1 (d) B2

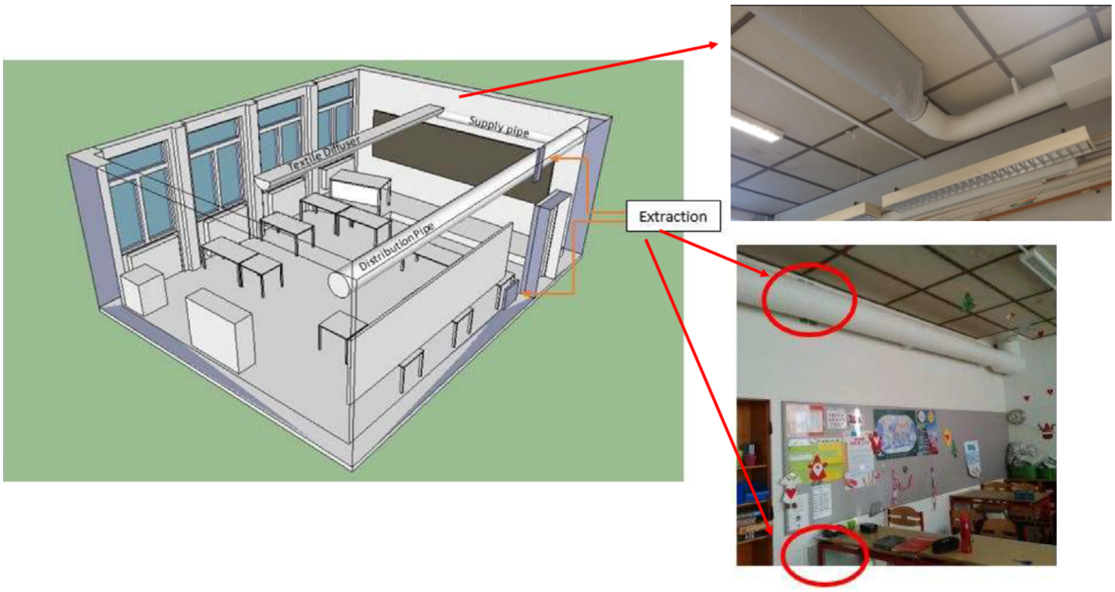


Figure 2. Mechanical ventilation in classroom A2 with textile diffuser and two exhaust openings

RESULT

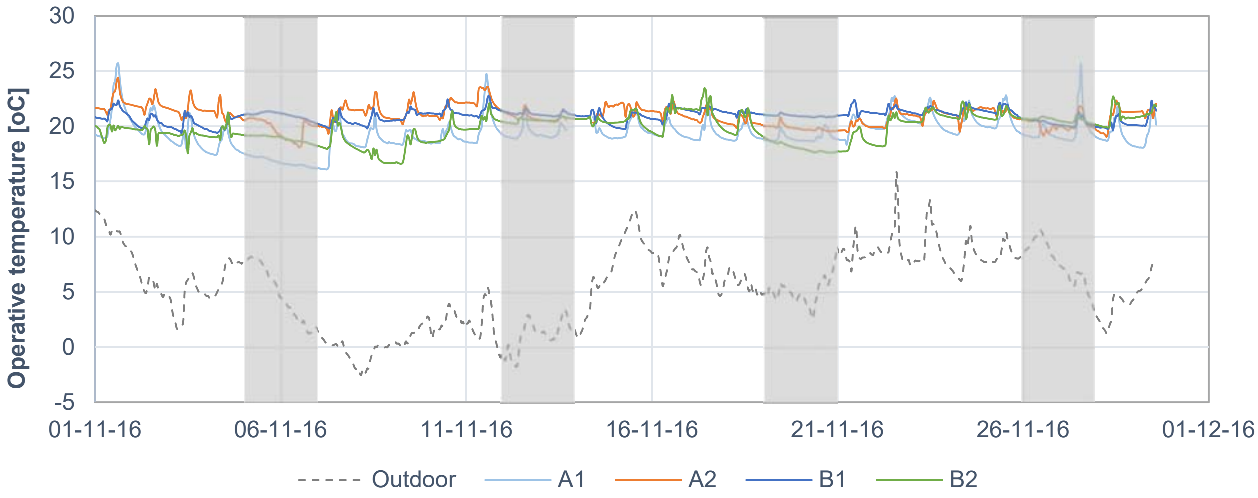
IEQ parameters

The indoor environment parameters monitored during November 2016 are illustrated in Figure 3. The monitoring was conducted during the heating season, and the operative temperature in the classroom should be within 20 – 25 ºC based on EN 15251 (2007) category II. Low operative temperatures were observed in Classroom A1 and B2 in the beginning of the occupied hours, which could be explained by the absence of the heat load during the unoccupied hours and people opened the window when they just arrived classroom to get fresh air. The high CO2 concentration is the major problem in the school environment. Even in the classroom with mechanical ventilation (A2), the CO2 level reached 2000 ppm during the occupied hours. The dissatisfied indoor air quality in A2 is due to the insufficient ventilation rate of mechanical ventilation system. Based on Danish Building Regulation (2015), the fresh air supply and extraction should be minimum 5 l/s per person plus 0.35 l/s per m2 floor area. Therefore, the required ventilation rate in classroom A2 is 1.9 l/s.m^2, which is triple of the existing ventilation rate 0.64 l/s.m^2. In all classrooms with natural ventilation, the peak CO2 concentration exceeded 3500 ppm. The worst air quality was found in classroom B2, where the CO2 reached 4500 ppm. The extremely high CO2 might due to the increase of people load in the classroom. The relative humidity has generally fulfilled the requirement (25-60%) in all the classrooms.

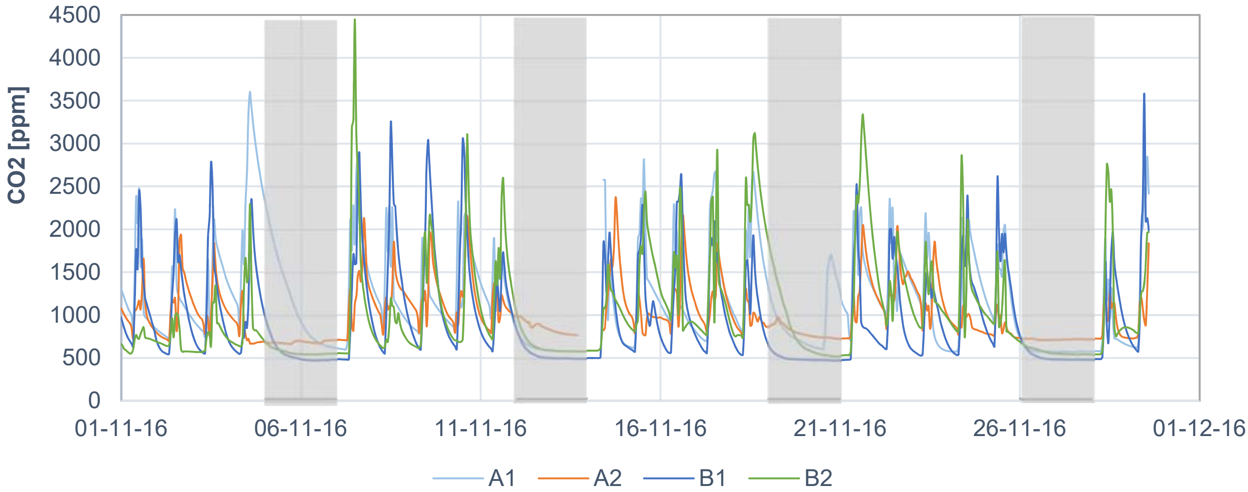
Table 2. Indoor environment and thermal comfort parameters during occupied hours

Room	Operative Temperature	CO2 concentration	Relative Humidity	Max Draught rate
A1	18.1 - 25.7 ºC	699 – 3603 ppm	30.7 – 64.5%	31.4%
A2	20.0 - 24.4 ºC	667 – 1964 ppm	23.3 – 51.7%	14.8 %
B1	19.4 - 22.7 ºC	483 – 3582 ppm	28.2 – 55.1%	10.4%
B2	16.9 - 23.4 ºC	554 – 4448 ppm	31.5 – 61.6%	39.4%

Draught is a common complaint in the ventilated room, especially in the winter season. The highest draught rate was found at 0.1 m height, which corresponds to the ankle level. Based on ISO 7730 (2005), draught rate should be limited to 20% in the classroom. However, draught rate reached 30 - 40% in the natural ventilated room (A1, B2). In order to get better indoor air quality, occupants will open the window regularly. The cold outdoor air blowing into the occupied zone becomes the major reason of draught.



(a)



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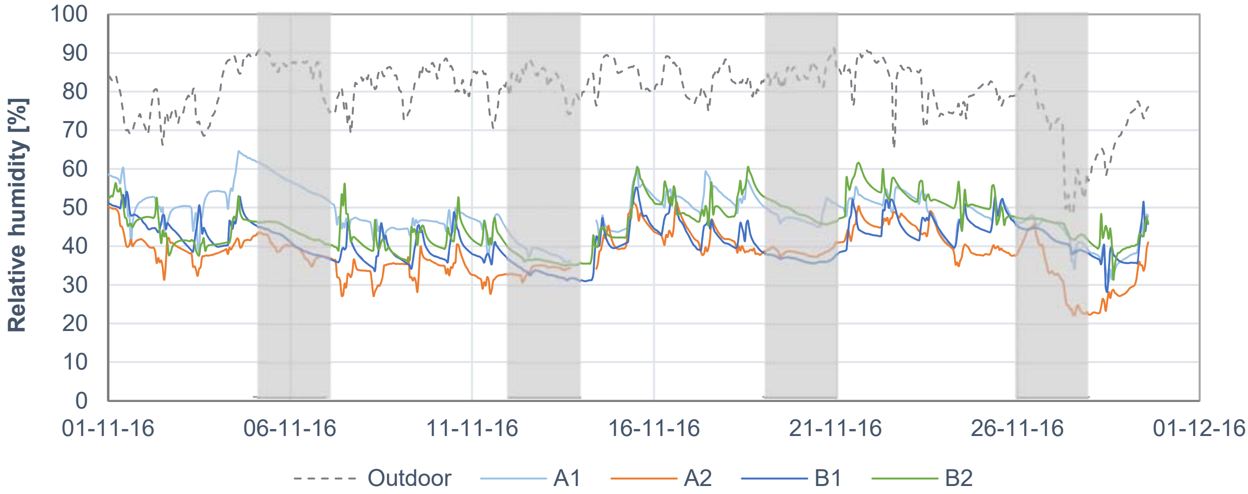

(c)

Figure 3. Indoor environment parameters for each classroom (a) Operative temperature (b) CO2 (c) Relative humidity (The gray column represented weekend)

Mechanical ventilation with textile diffuser

Special attention has been paid on the performance of the mechanical ventilation system with a textile diffuser in Classroom A2. Detailed measurement of air temperature and air velocity were conducted at the different height along the length of the textile diffuser, as indicated in Figure 4.

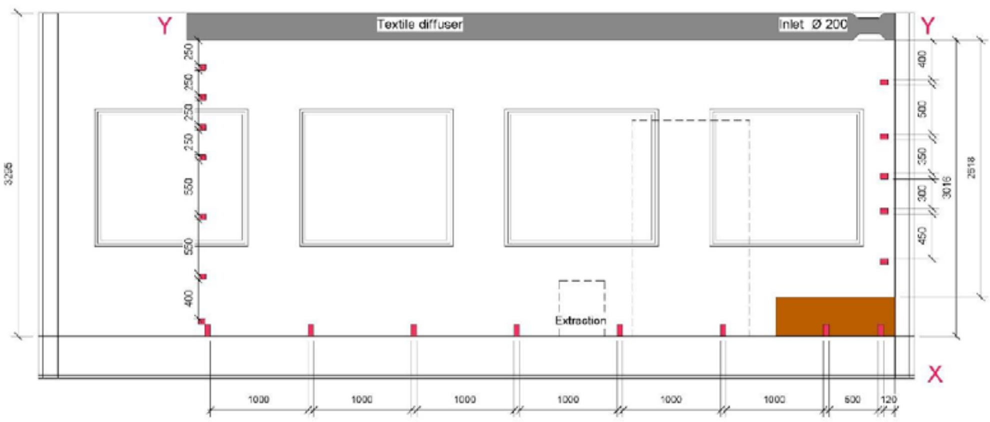

Figure 4. Measurement of textile diffuser performance, cross section

The high velocity below the textile diffuser at 10 cm and 50 cm to the front wall indicated that a large amount of air was supplied to the room near the inlet of the textile diffuser. However, the air velocity became uniform below 2 m height, which indicated a good mixing has been reached in the occupied zone. On the other hand, the temperature distribution was very uniform in the occupied zone where students located, while the higher temperature was found at the platform where teacher located. The higher temperature at platform might due to the heat load from the computer or the equipment used by the teacher.

Generally, a good mixing had been reached in the classroom, especially where students located. As stated by P. Nielsen (2008) that the air distribution in the room is strongly related to the location of the textile diffuser. A good mixing will occur if the diffuser is directly placed above the heat source, while displacement effect will occur if the diffuser is located close to the side-wall.

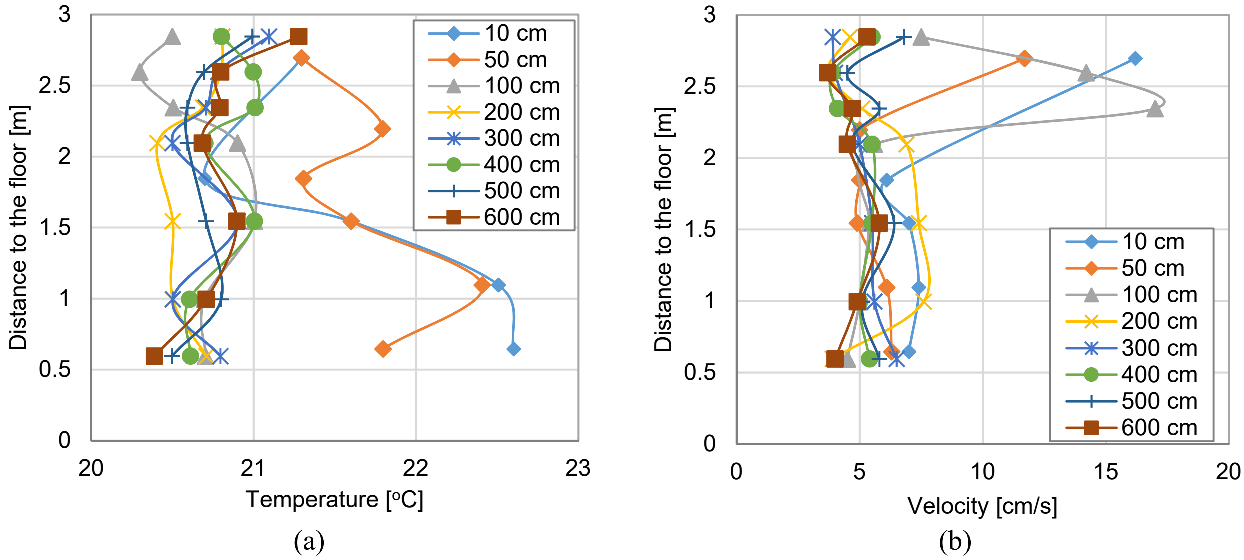

Figure 5. Temperature and velocity profile below textile diffuser

The placement of exhaust opening in Classroom A2 was not well designed, as shown in Figure 2. There are two exhaust openings. One is blocked by the ventilation pipe and the other is blocked by the furniture. The reduced outlet area led to a significant increase of fan power and higher air velocity near the exhaust. Especially the student sat near the exhaust will have draught risk.

The mechanical ventilation system was original with a heat recovery unit. However, the heat recovery unit was compromised one winter due to a frozen pipe and never been replaced. Instead, an electrical heating coil was added to preheat the fresh air.

CONCLUSIONS

This study explores the indoor environment in the school buildings and its relation with ventilation strategies. The measurement results show that high CO2 contentment was found in all the monitored classrooms. The low indoor temperature was observed in the naturally ventilated classrooms at the beginning of the occupied hours, might due to the lack of heat load during the night or people open the window to get fresh air when they just arrive the classroom. At the same time, high draught rate was observed in the classroom with natural ventilation due to cold outdoor air into the room by opening windows.

On the other hand, the mechanical ventilation system was not well designed and maintained in the school building. Insufficient fresh air and extraction were observed in the classroom A2, which was only one-third of the required ventilation rate based on Danish building regulation. The exhaust openings were blocked either by ventilation pipe or by furniture, which significantly reduced the outlet area and increased the draught risk of the students sat nearby. The heat recovery unit did not function as designed due to improper operation and maintenance, which results significantly increase of energy consumption of ventilation system.

Although the number of monitored classrooms was limited in this study, the results indicated that insufficient ventilation and the poor indoor environment is a major problem of Danish schools. The current natural ventilation or CAV system is not efficient from both indoor environment and energy aspects. Demand controlled mechanical ventilation system with high-efficiency heat recovery unit should be recommended when building new or renovating school buildings.

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